MPI@LHC 2018

Prospects and results from the PPS detector

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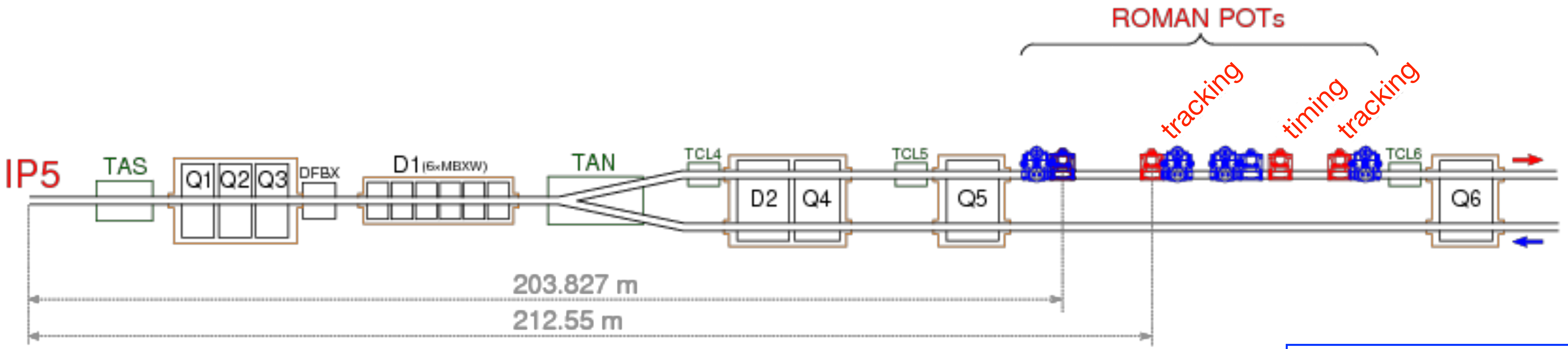
on behalf of the CMS Collaboration

The PPS project



CERN-LHCC-2014-021

Originally developed as a joint CMS-TOTEM project (CT-PPS)

Detectors located in pre-existing TOTEM horizontal roman pots + new dedicated ones along the LHC beam line, at ±~200 m from the CMS interaction point

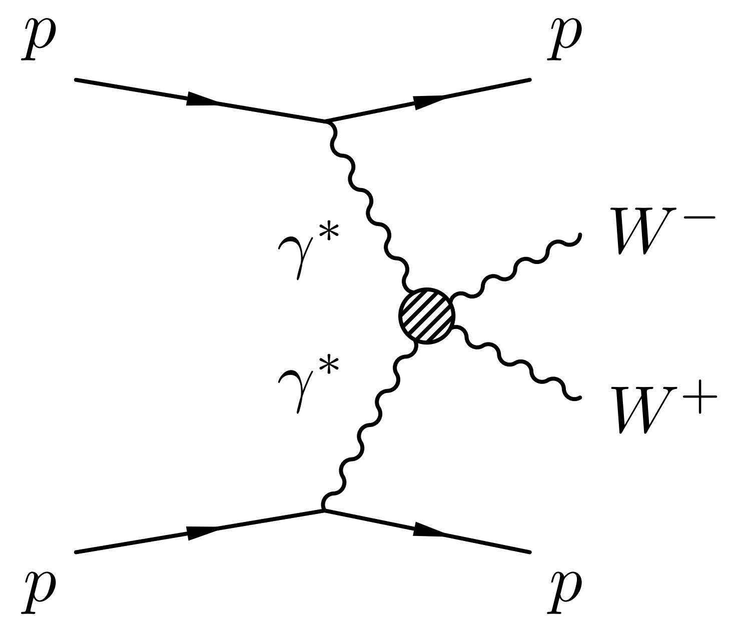
- two tracking stations and one timing station per side

Detects intact protons emerging from the IP and driven by LHC magnets in proximity of the proton beam ⟹ detectors approaching the beam at ~1 mm

Designed to operate continuously at standard LHC running conditions

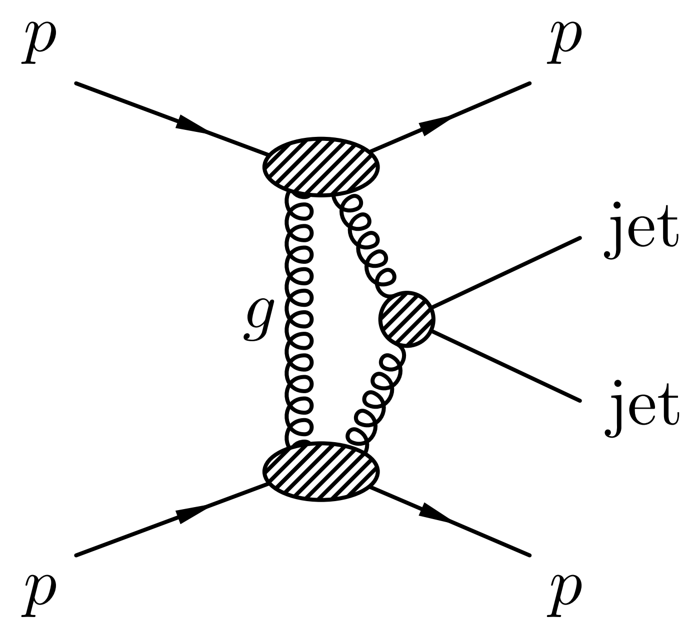
The PPS physics program

Main target of the PPS physics program is the study of Central Exclusive Production (CEP) processes, where both protons remain intact and get detected in the roman pots.



Electroweak physics ("γγ collider")

- dilepton/diboson production: $\gamma\gamma \to W^+W^-$, $\ell^+\ell^-$ ⟹ search for anomalous quartic gauge couplings (AQGC)
- search for SM-forbidden couplings: γγγγ, ZZγγ

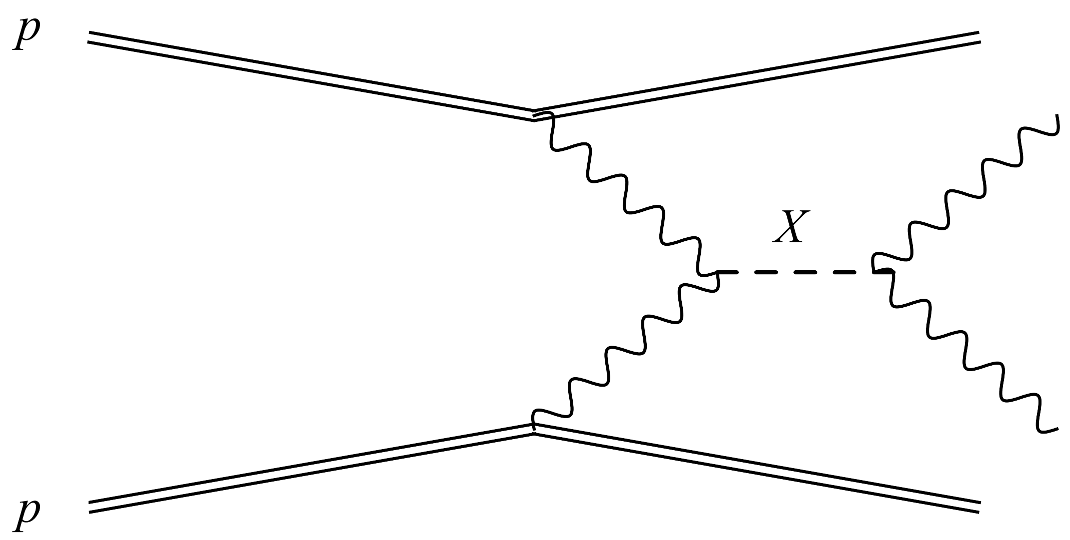


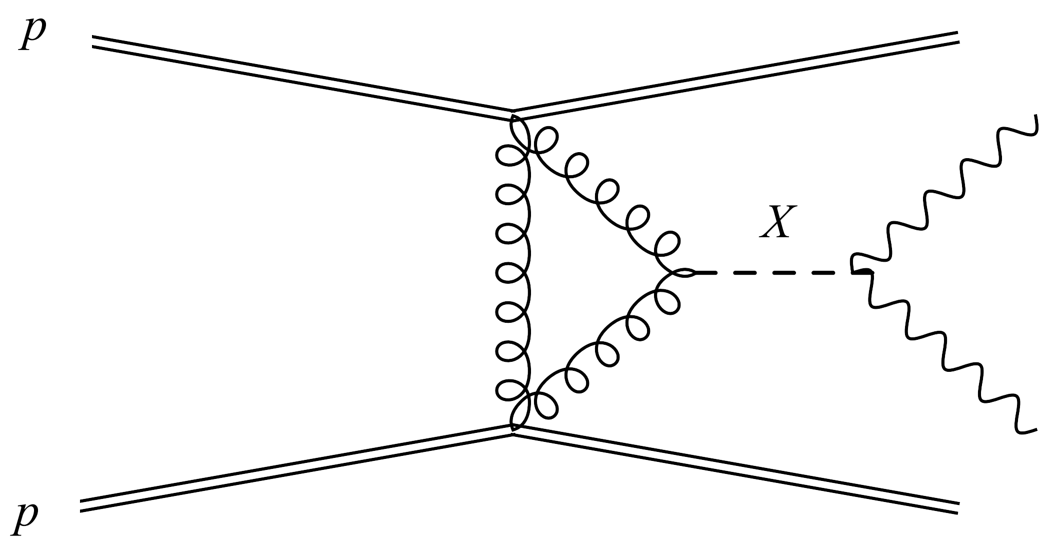
QCD ("gg collider")

- pQCD tests of exclusive production
- characterisation of gluon jets (small quark component)

Search for New Physics

- CEP of new resonances
- search for invisible decays

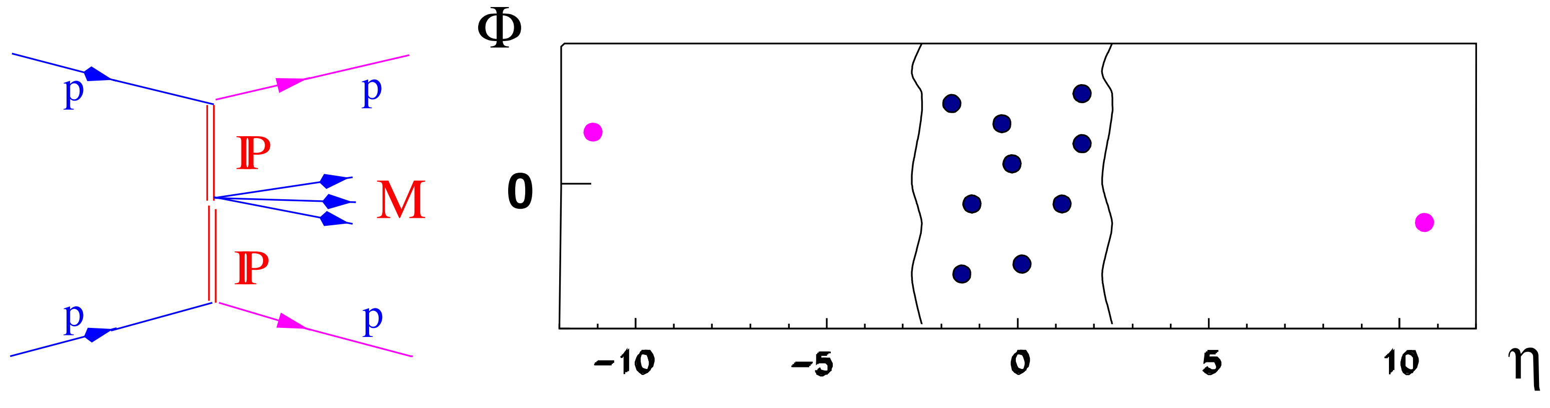


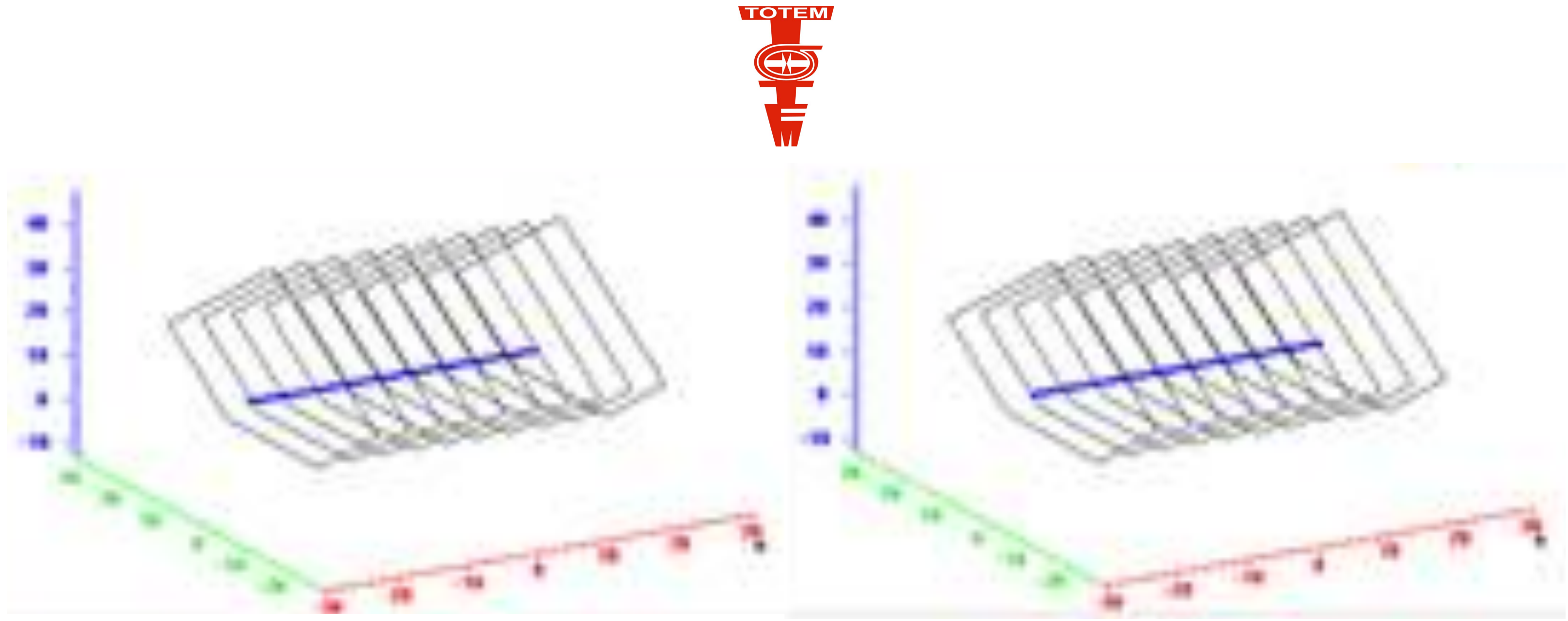


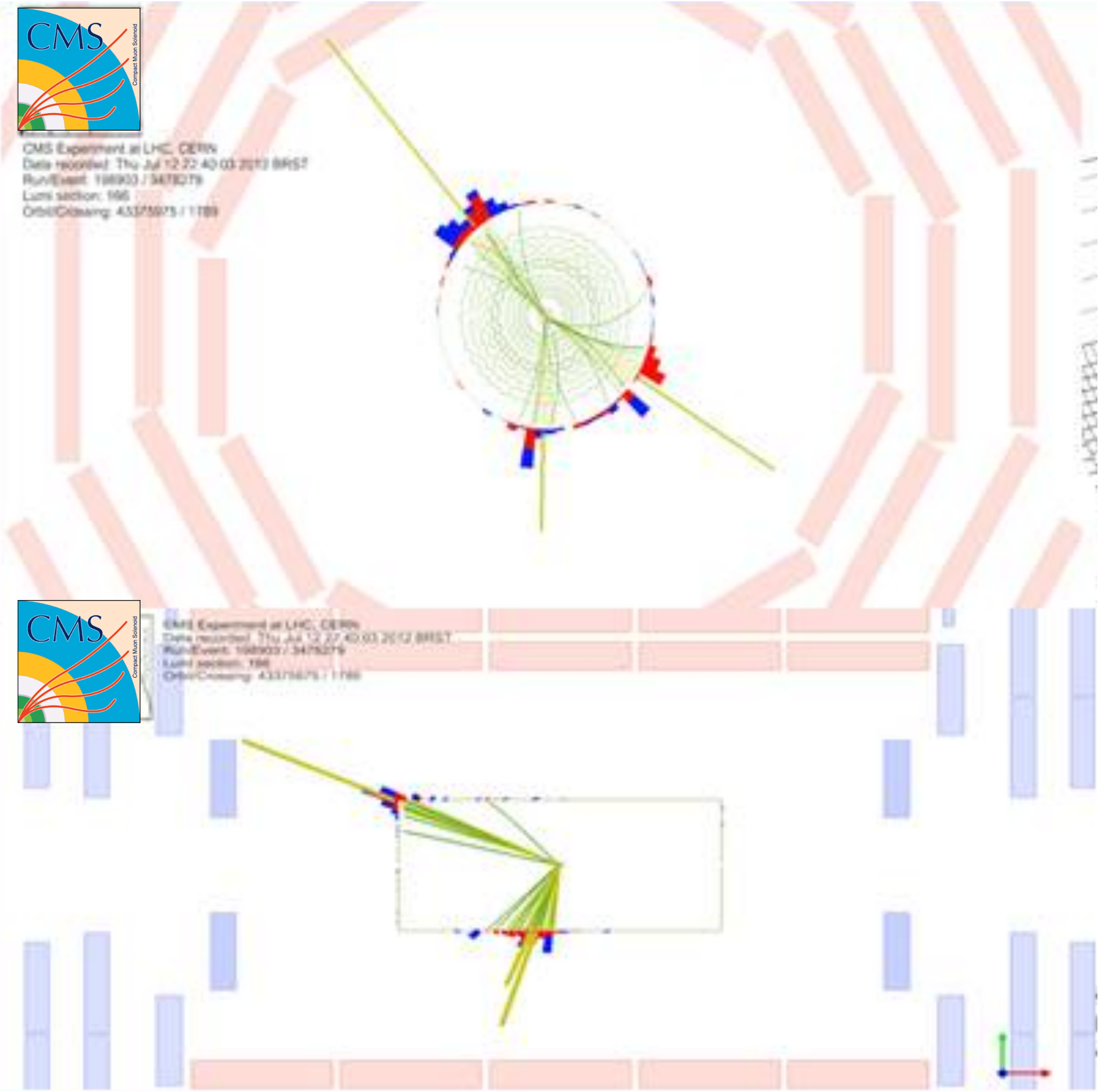
Event signature

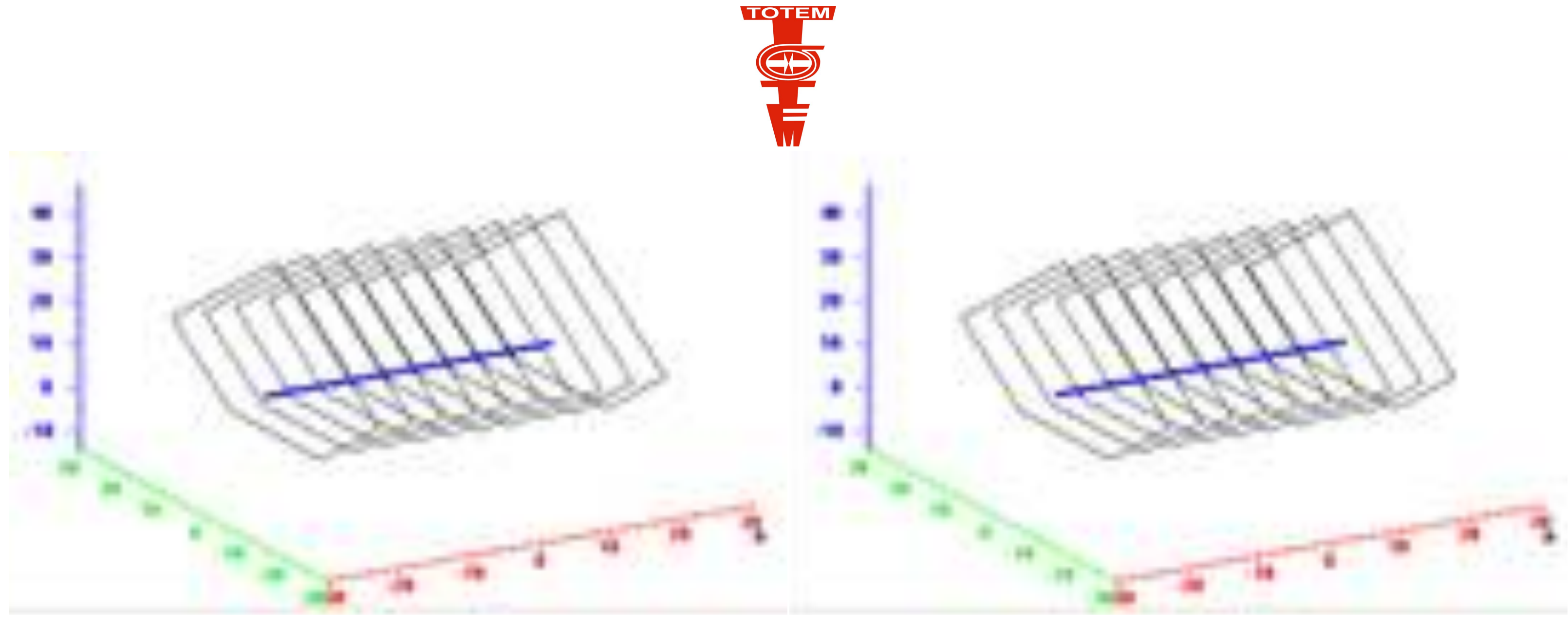
Events of interest characterised by distinct signature:

- two leading protons reconstructed on opposite sides of the IP;
- large rapidity gap between central system and leading protons (colour-singlet exchange);
- possibility to “close” the event by matching central system and leading protons kinematics









from CMS + TOTEM low luminosity run, for illustration purposes only

Proton kinematics

Proton kinematics defined by:

- four-momentum transfer squared, $t \equiv (p_f - p_i)^2$;
- fractional momentum loss, $\xi \equiv (|\mathbf{p}_f| - |\mathbf{p}_i|)/|\mathbf{p}_i|$

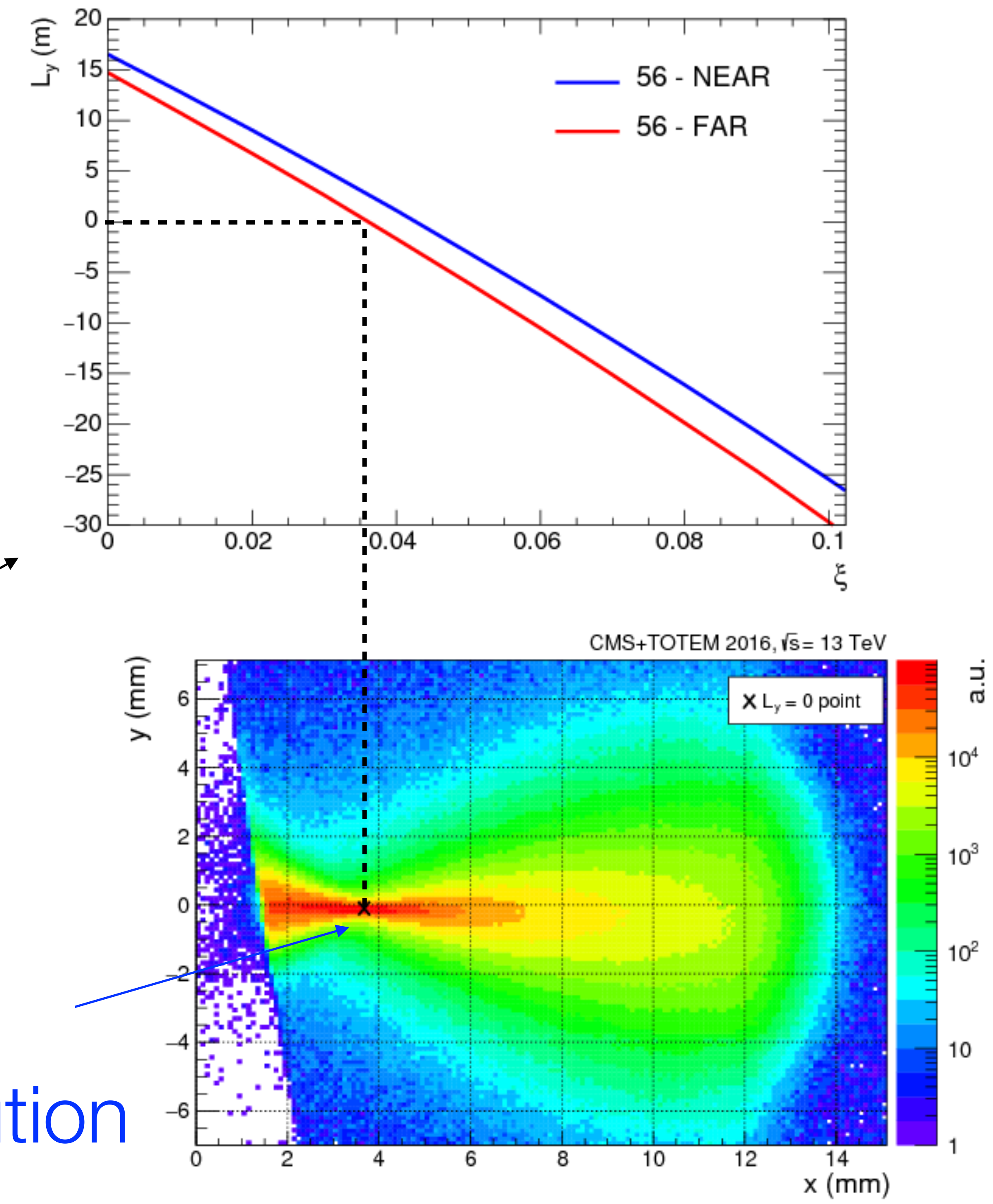
Proton acceptance in the detectors depends on the machine optics parameters:

measured at RP — values at IP

$$\begin{pmatrix} x \\ \theta_x \\ y \\ \theta_y \end{pmatrix} = \begin{pmatrix} v_x & L_x & m_{13} & m_{14} & D_x \\ v'_x & L'_x & m_{23} & m_{24} & D'_x \\ m_{31} & m_{32} & v_y & L_y & D_y \\ m_{41} & m_{42} & v'_y & L'_y & D'_y \end{pmatrix} \begin{pmatrix} x^* \\ \theta^*_x \\ y^* \\ \theta^*_y \\ \xi \end{pmatrix}$$

Leading terms for "standard" LHC optics:

- $x \approx D_x(\xi)\, \xi$
- $y \approx L_y(\xi)\, \theta_{y^*}$



"waist" in proton
impact point distribution

Proton acceptance

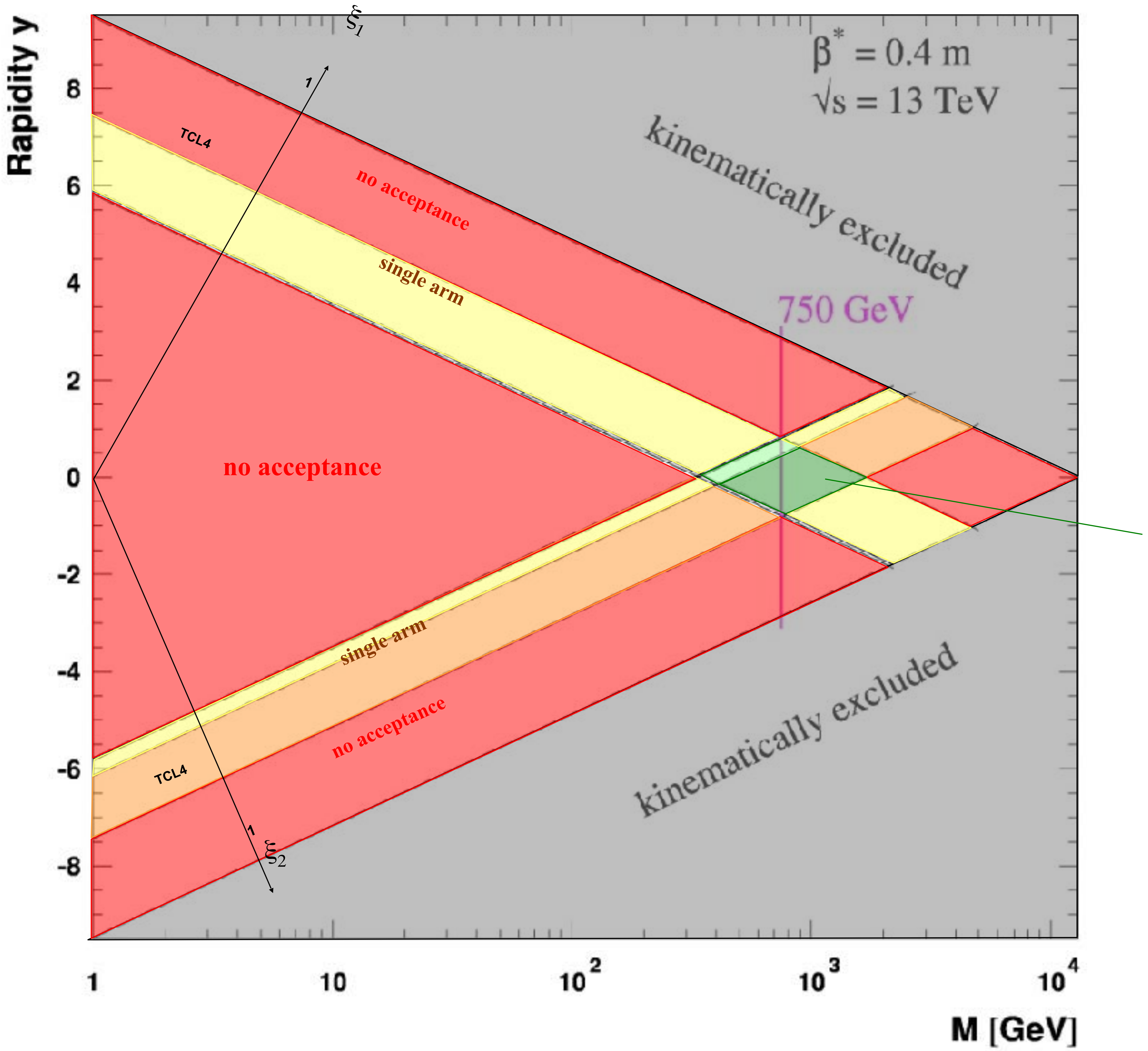
Mass and rapidity of the central system related to the protons ξ:

- $M^2_X = s\xi_1\xi_2$;
- $y = 1/2 \ln(\xi_1/\xi_2)$

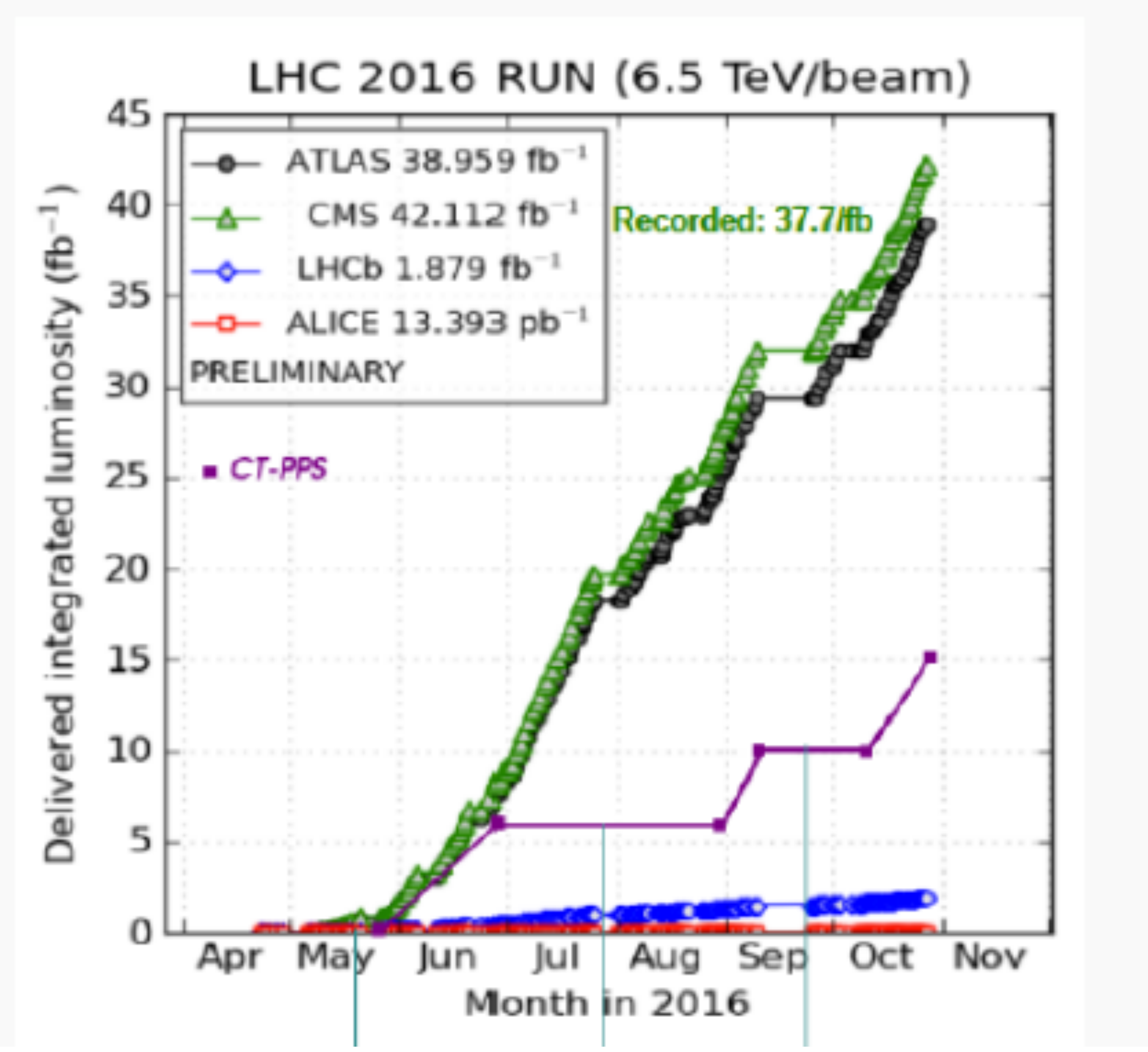
$\Longrightarrow$ powerful matching requirement

Proton acceptance depends on the machine optics (mainly D_x) and on minimum attainable distance of detectors from beam

In 2016, maximum acceptance (~30%) for $M_X \approx 750$ GeV



Data taking in 2016 and 2017



Start of CT-PPS data taking advanced to 2016:

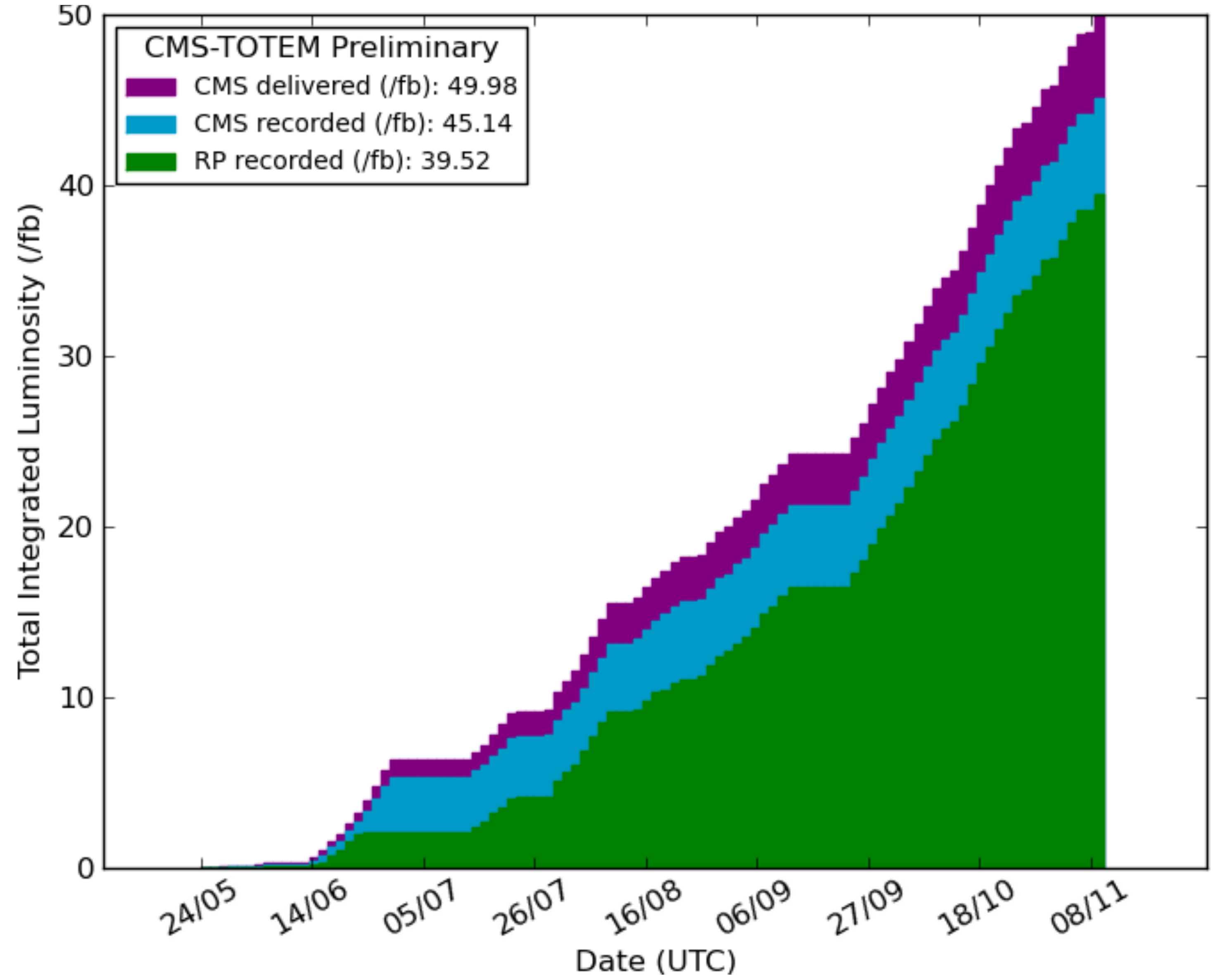
- TOTEM silicon strip detectors used for tracking;
- diamond detectors (developed for TOTEM) in timing stations

~15 fb^{-1} of data recorded with tracking roman pots inserted

2017: towards design detector configuration

- tracking: per each side, one station with silicon strips, one station with 3D silicon pixels;
- timing: per each side, one mixed diamond - silicon (UFSD) station

~40 fb^{-1} of data recorded with roman pots inserted



Data taking in 2018

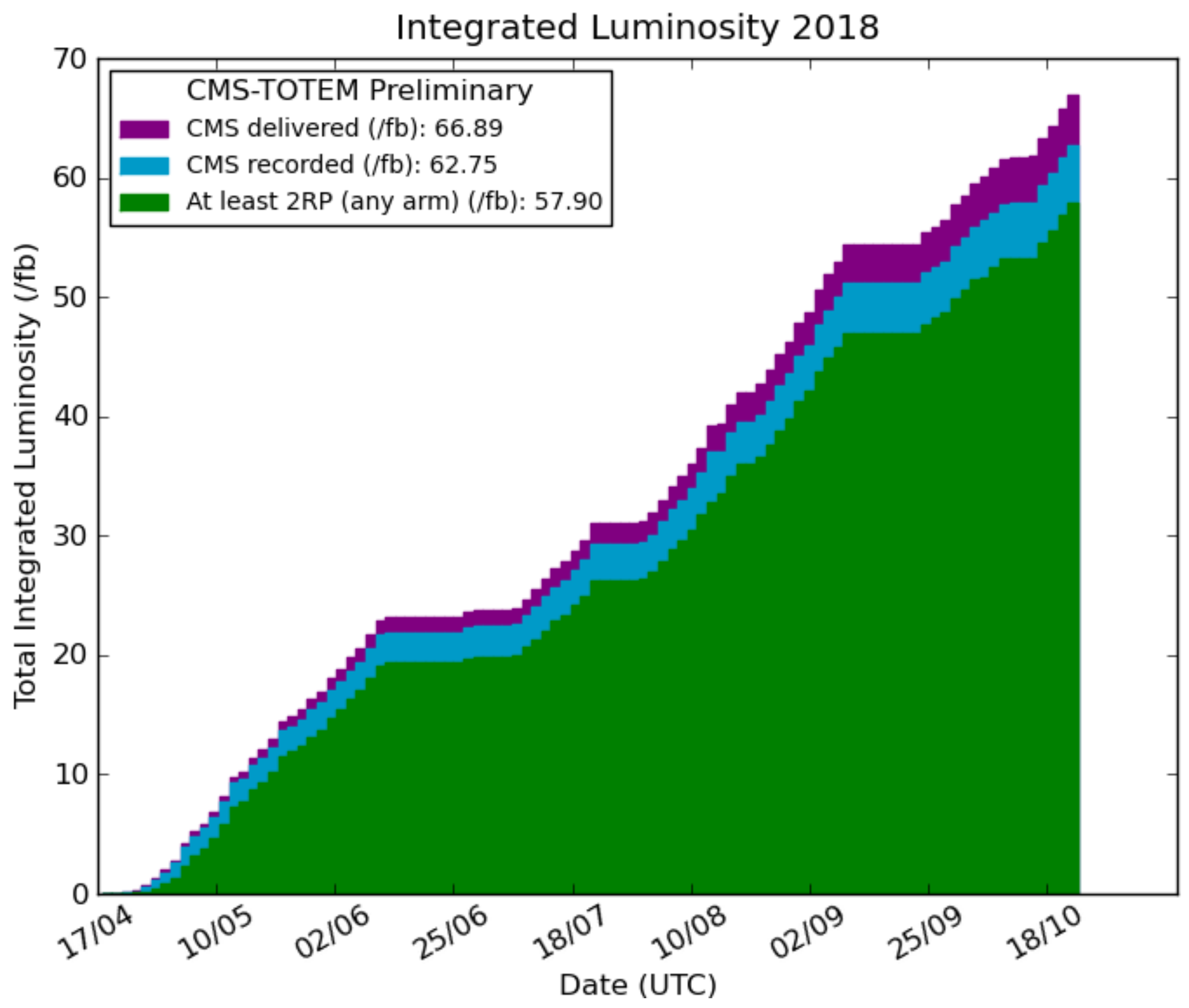
Detectors

- Tracking: design configuration, all stations equipped with 3D silicon pixel detectors (2 per side)
- Timing: stations equipped with diamond and double-diamond detector layers (1 station per side)

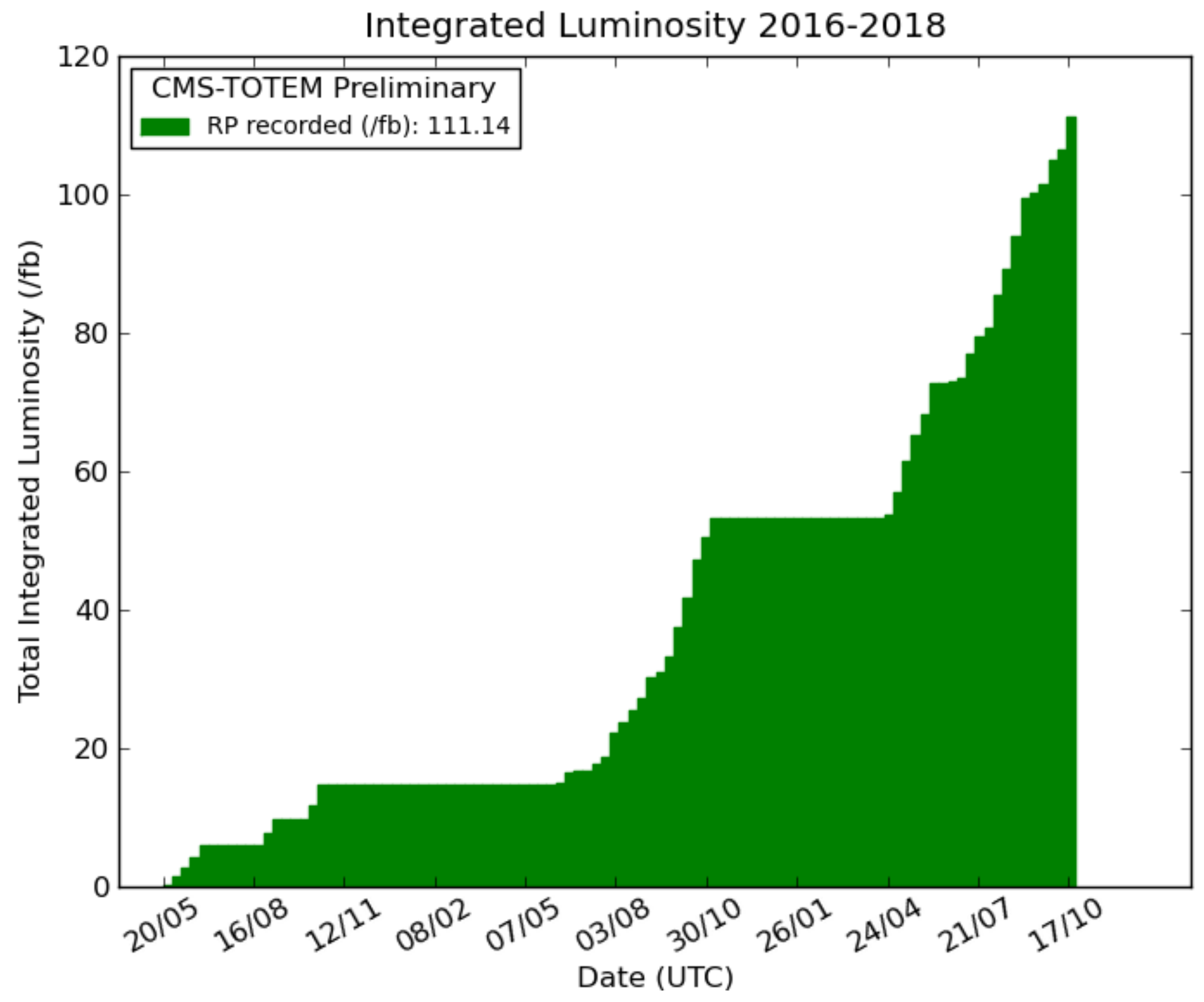
Roman pots regularly inserted in LHC fills

- data taking time almost superimposed to that of CMS

~58 fb^{-1} of data recorded



PPS integrated luminosity in all Run 2: ~110 fb^{-1}

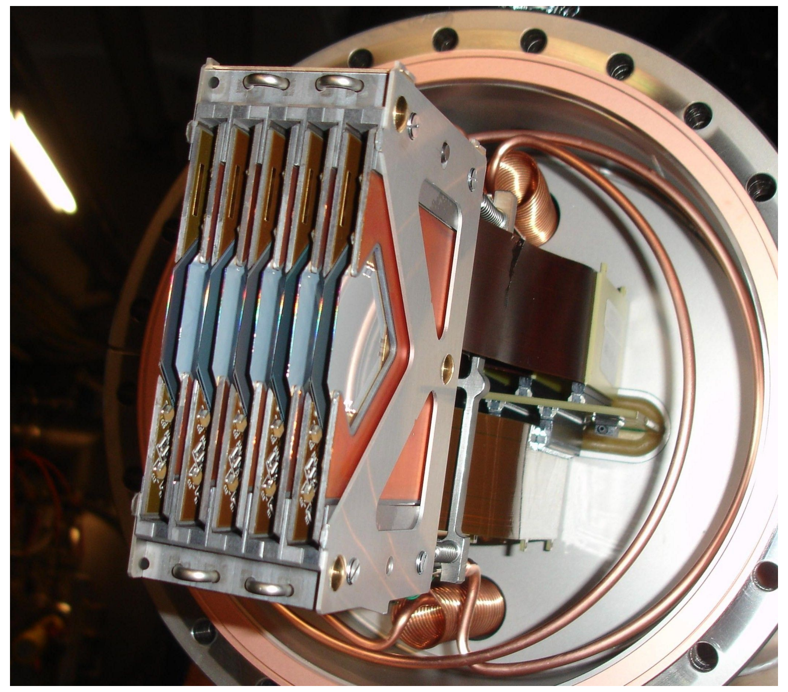


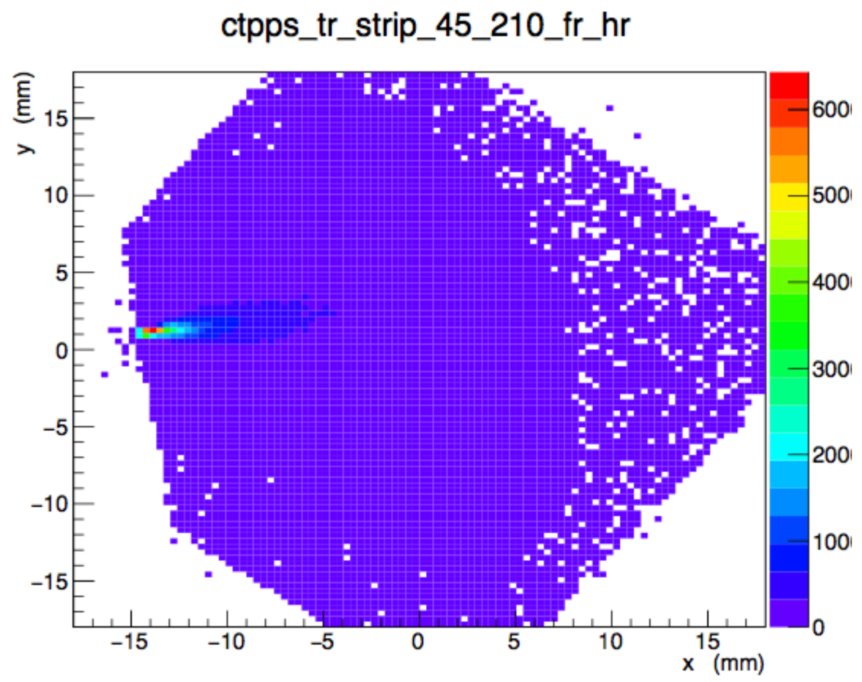
LHC "dynamic" beam settings

- luminosity levelling through multi-step β^* and crossing angle tuning

Tracking detectors

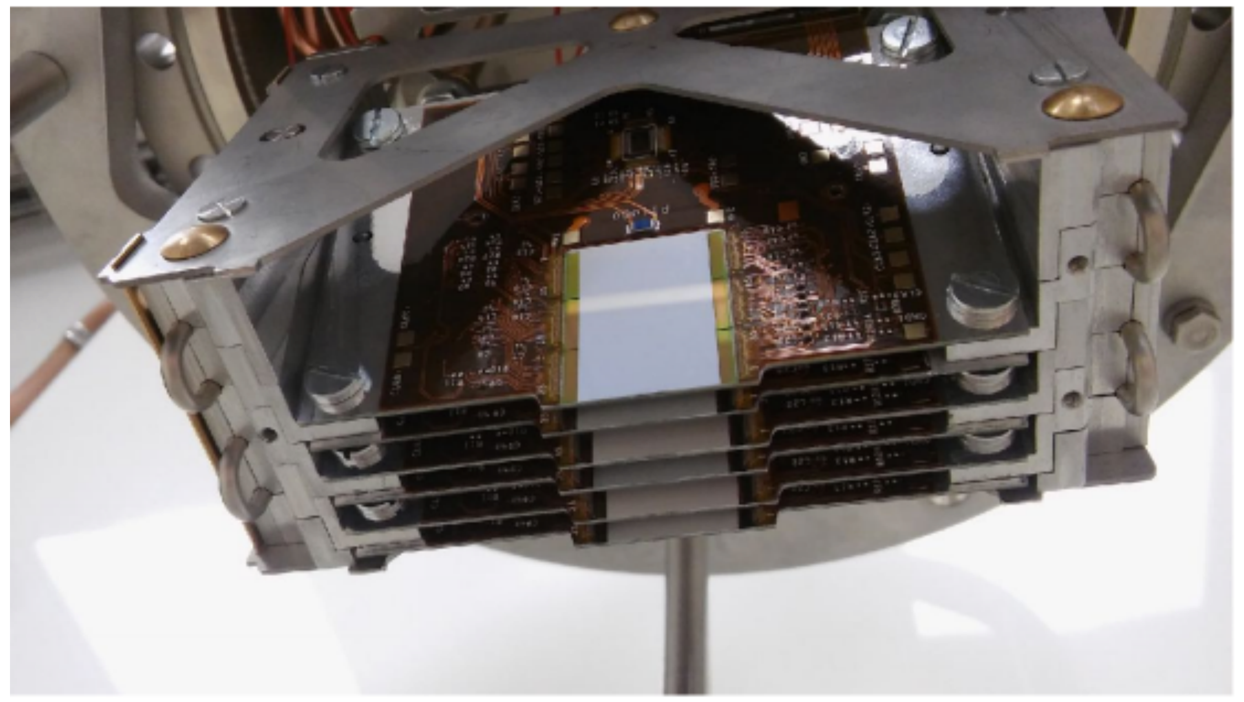
Silicon strips

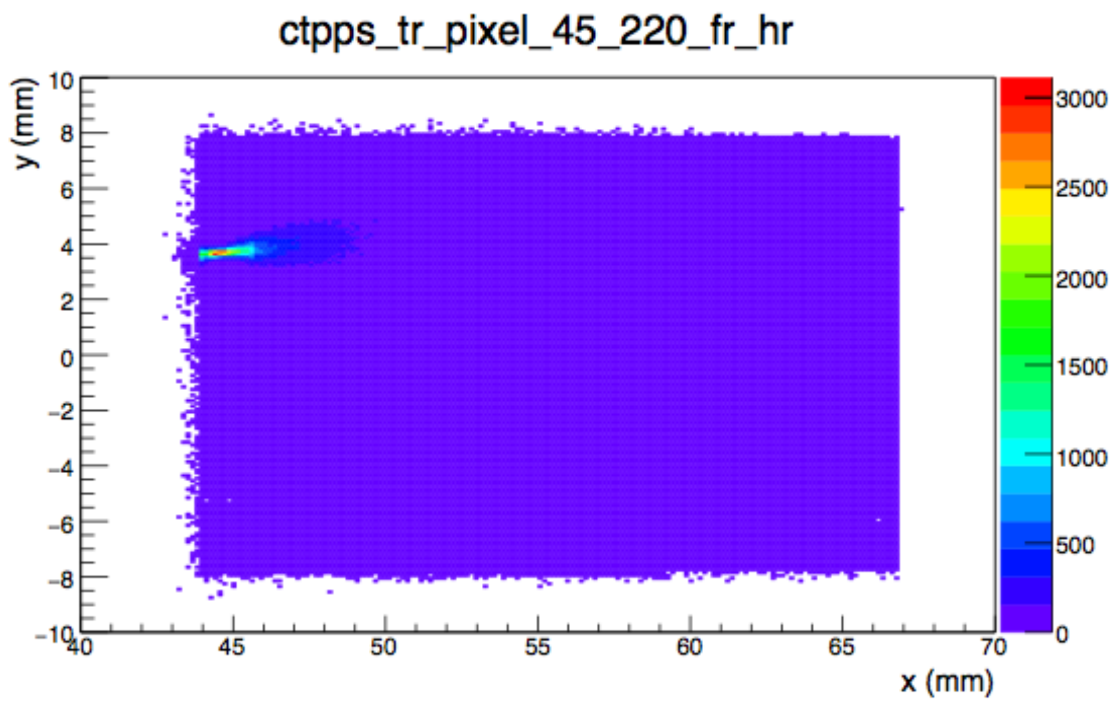




- 10 planes per station of "edgeless" silicon strip detectors (5 '*u*' + 5 '*v*')
- pitch: 66 μm; track resolution: ~12 μm
- designed for low-luminosity running (TOTEM)

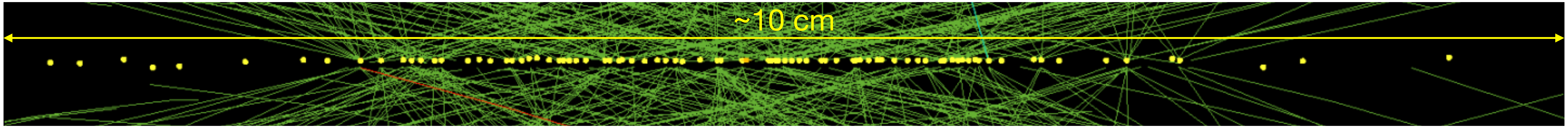
Silicon pixels





- 6 planes per station of "slim-edge" silicon pixel detectors with 3D technology (tilted by ~18º)
- pixel size: 100 μm × 150 μm; track resolution ~20 μm
- designed for high-luminosity running ⟹ multi-track capability

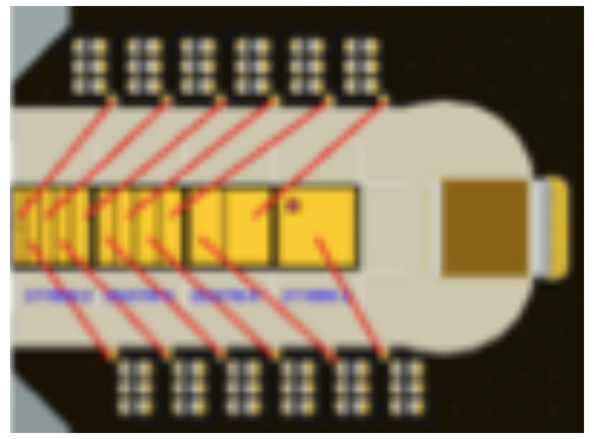
Timing detectors



TOF measurement to reduce background from pileup (uncorrelated proton tracks)

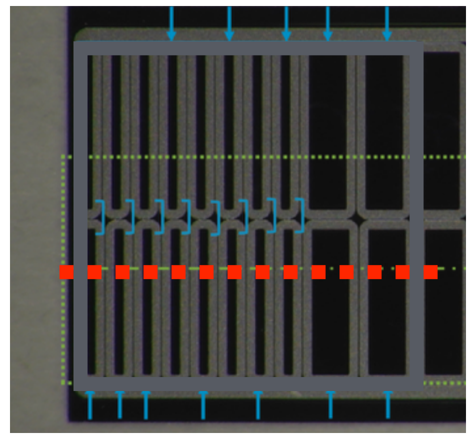
- Ideally, desired resolution $\sigma_t \approx 20$ ps $\Longrightarrow \sigma_z \approx 4$ mm

Diamond sensors



- 4 planes (3 in 2017) of CVD diamond sensors
- macro-pixels of varying size
- single-plane resolution target: ~80 ps
- 2+2 double-diamond layers in 2018 (larger signal expected $\Longrightarrow$ faster rise time)
- radiation hard

Ultra-Fast Silicon Detectors



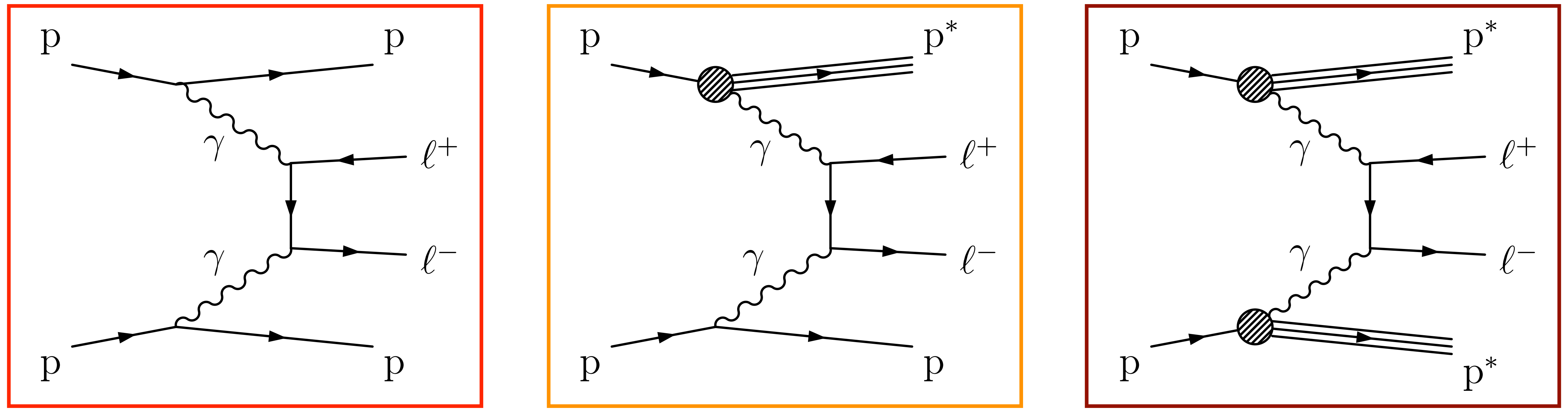
- 1 plane (in 2017) of UFSD, based on LGAD technology
- single-plane resolution in test beam: ~30 ps
- R&D to improve radiation hardness

Common readout electronics

Central dilepton production

Search for a centrally produced pair of oppositely charged leptons with forward proton tag

- photon-photon fusion process, never observed before
- test of theoretically clean exclusive cross section
- benchmark for similar searches of centrally produced high mass objects (e.g. W^+W^-)



Signal

- central exclusive production: small cross section for CT-PPS central mass range ($m(\ell^+\ell^-) \gtrsim 400$ GeV)
- single dissociation (SD): broader ξ range

Background

(in coincidence with unrelated proton from pileup or beam background)

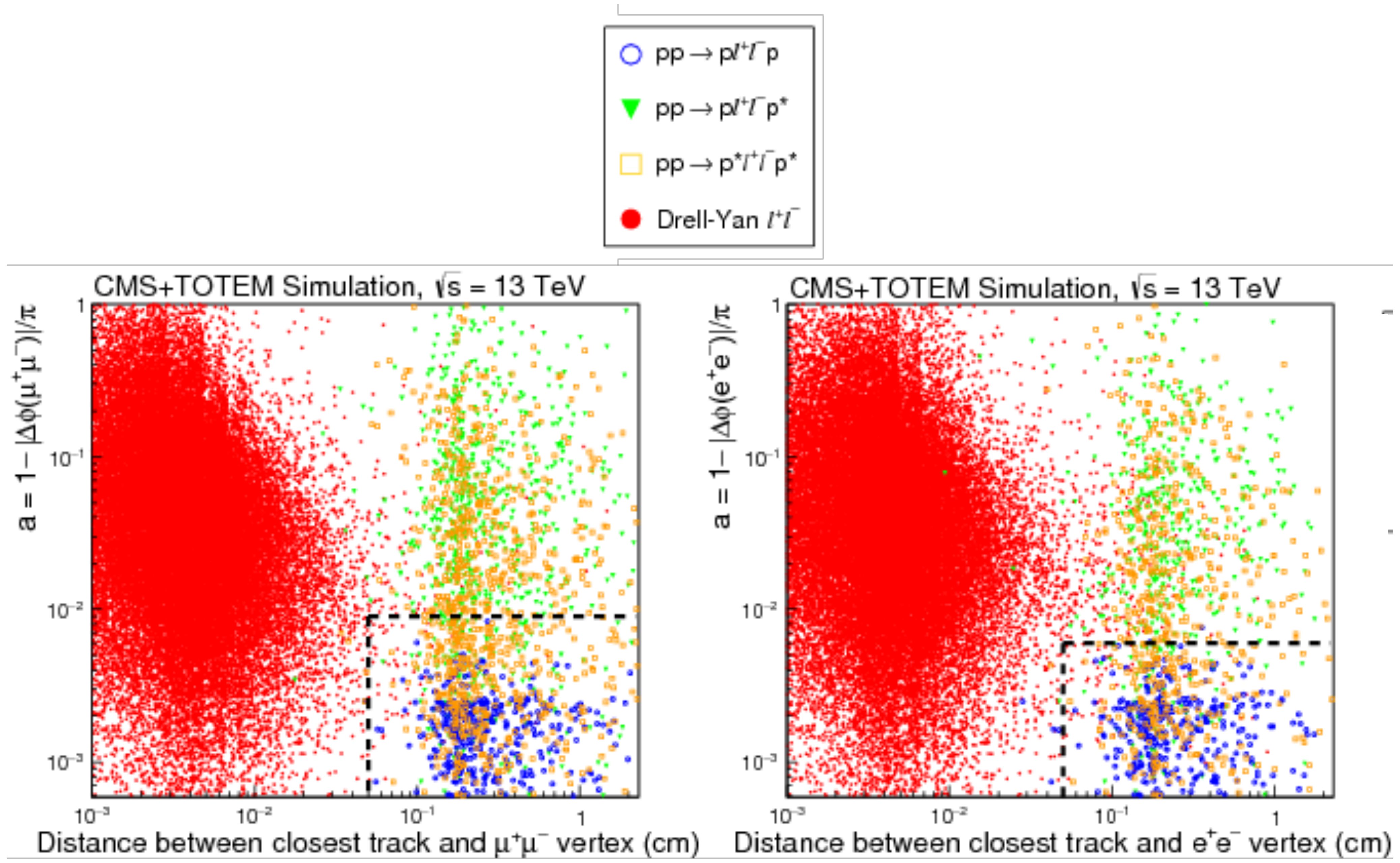
- double dissociation (DD)
- inclusive Drell-Yan processes: $pp \to \gamma^* Z^* \to \ell^+\ell^- + X$

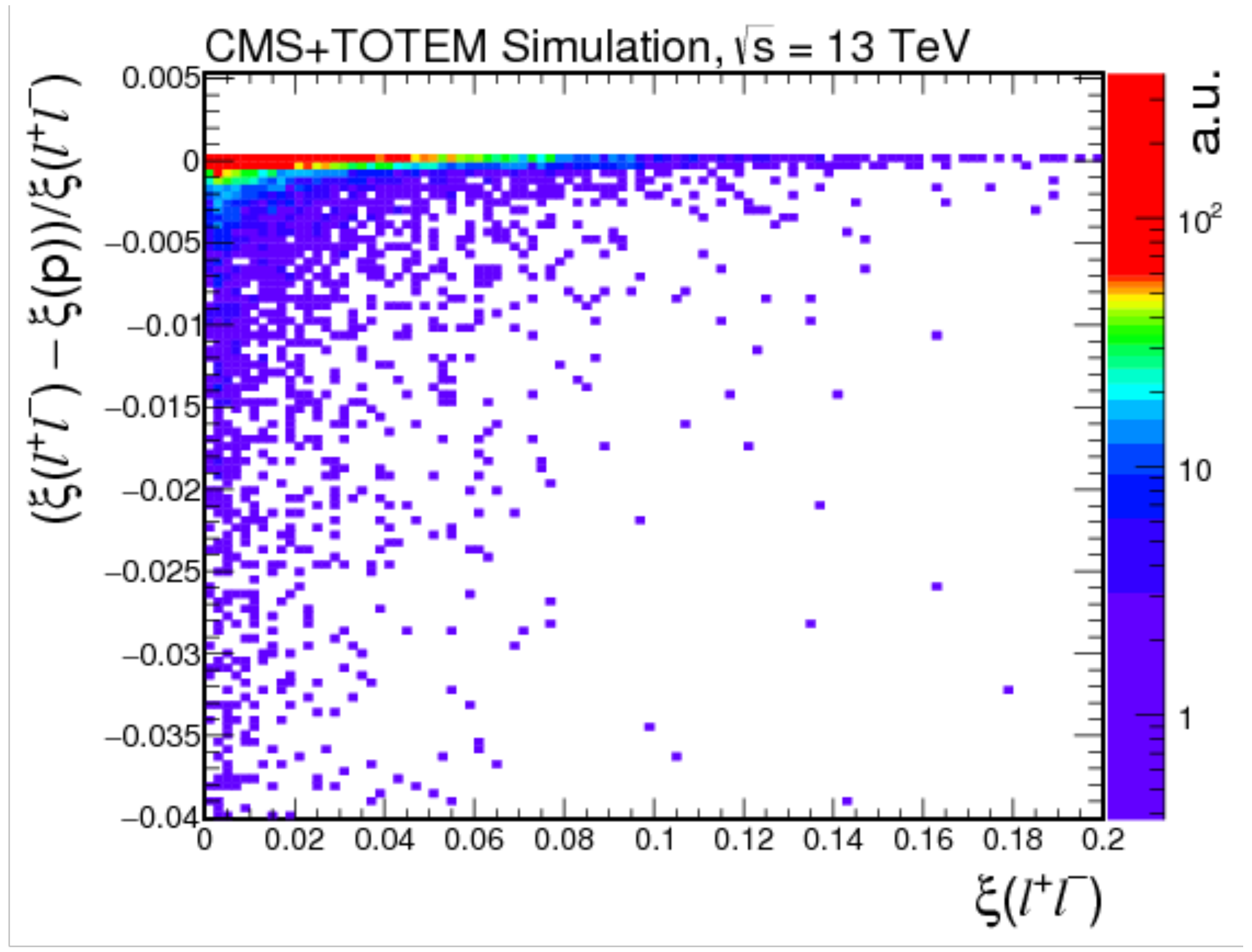
Analysis performed on 9.4 fb^{-1} of data at 13 TeV collected in 2016 (only tracking)

Event selection

Dilepton selection:

- Trigger: two muons (electrons) with $p_T > 38$ (33) GeV
- Dilepton vertex consistent with primary interaction
- "Good" leptons with $p_T > 50$ GeV and opposite charge
- Combined selection on distance of closest track to vertex and acoplanarity $a = 1 - |\Delta\phi(\ell^+\ell^-)|/\pi$
- $m(\ell^+\ell^-) > 110$ GeV





Matching of central and proton kinematics:

- at least one proton track
- ξ from central system: $\xi(\ell^+\ell^-) = \frac{1}{\sqrt{s}}\left[p_T(\ell^+)e^{\pm\eta(\ell^+)} + p_T(\ell^-)e^{\pm\eta(\ell^-)}\right]$

  (exact for exclusive, mostly within resolution for single dissociation events)
- signal region defined by $\xi(\ell^+\ell^-) - \xi(p)$ match within 2σ

Background estimate

Background mostly due to Drell-Yan or double dissociation events with unrelated proton track from pileup or beam background

- mostly data-driven estimate

	Contribution	After preselection	After kinematic match
Muons	Drell-Yan	11.36 ± 0.18	1.38 ± 0.06
	DD	1.17 ± 0.02	0.108 ± 0.005
	Total	12.52 ± 0.18	1.49 ± 0.07
	Observed	17	12
Electrons	Drell-Yan	12.33 ± 0.19	2.30 ± 0.09
	DD	0.56 ± 0.01	0.067 ± 0.003
	Total	12.89 ± 0.18	2.36 ± 0.09
	Observed	23	8

⟹ 5.1 σ excess over background

- no events with matching protons in both arms

First observation of proton-tagged γγ collisions at the electroweak scale

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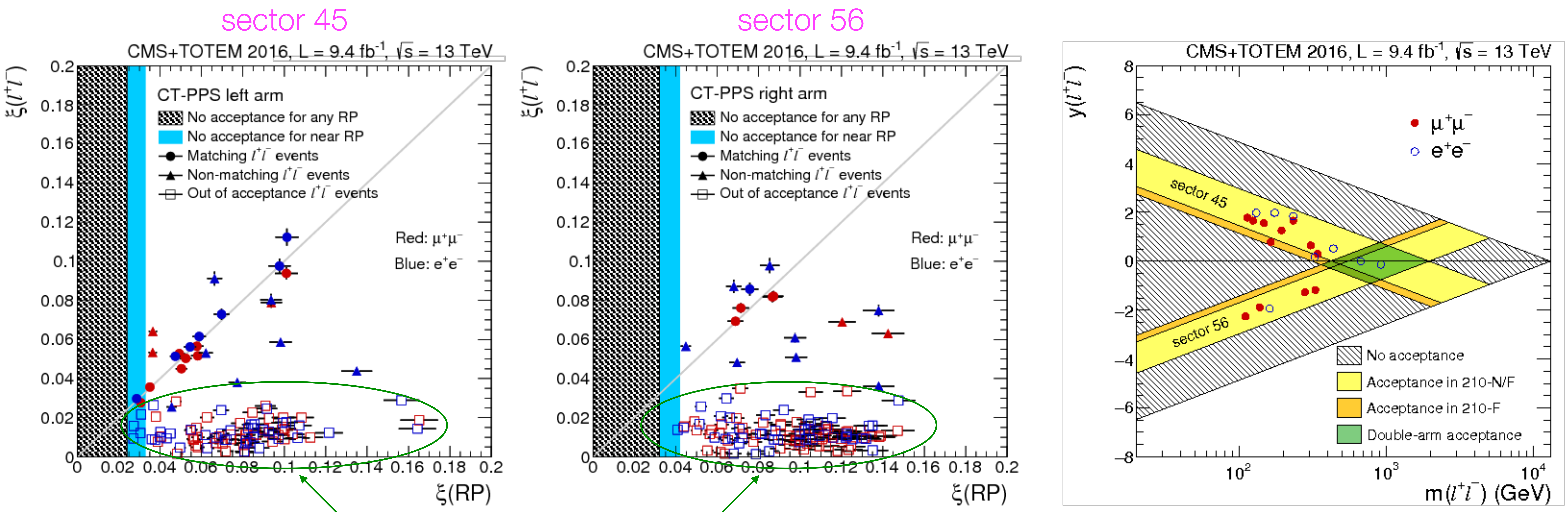
Kinematics of signal events



$\xi(\ell^+\ell^-)$ out of proton acceptance

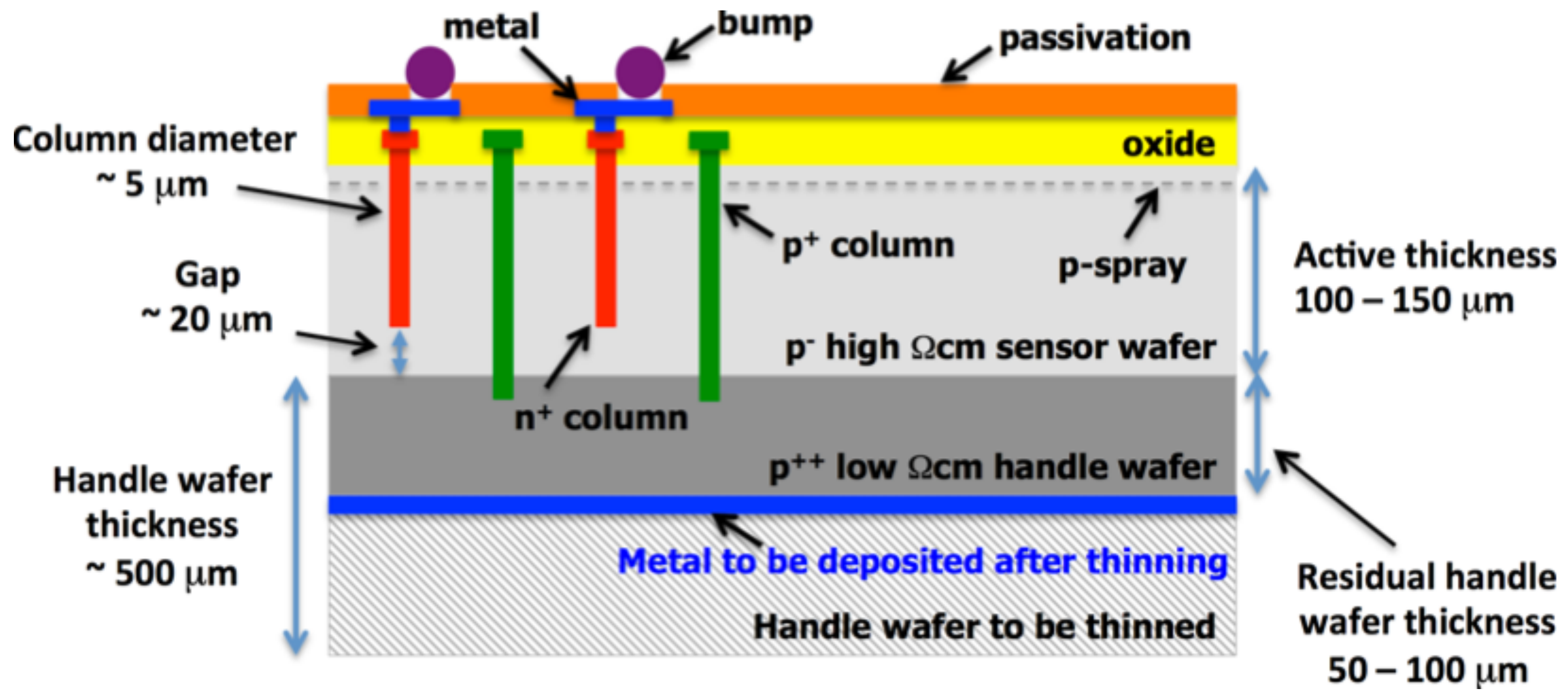
No exclusive production event (double proton tag) observed

- consistent with MC predictions

Prospects for LHC Run 3

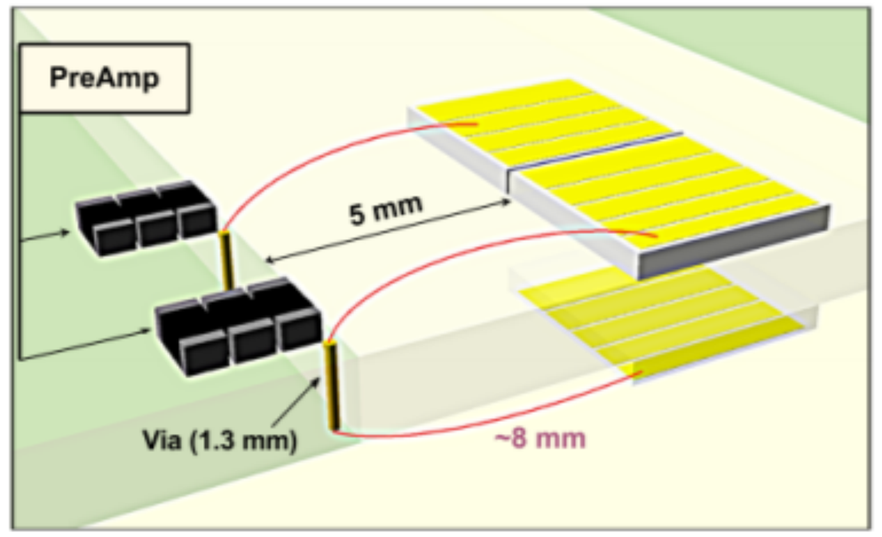
Continuation of the PPS program has been approved for LHC Run 3 (2021-2023) at $\sqrt{s}$ = 14 TeV

New detectors needed, to replace current ones damaged by radiation



Tracking: new 3D silicon pixel detectors

- technology very similar to existing one
- same geometry/granularity



Timing: double diamond sensors

- proposal to double the number of timing stations

LHC luminosity levelling pushed forward

⟹ nearly continuous variation of machine optics parameters: reconstruction will have to follow

Summary and plans

PPS has demonstrated the feasibility of studying forward proton-tagged events at high luminosity

First observation of central (semi)exclusive production of high mass lepton pairs

Total data sample of ~110 fb^{-1} collected in Run 2 (2016-2018)

Several analyses currently ongoing or starting

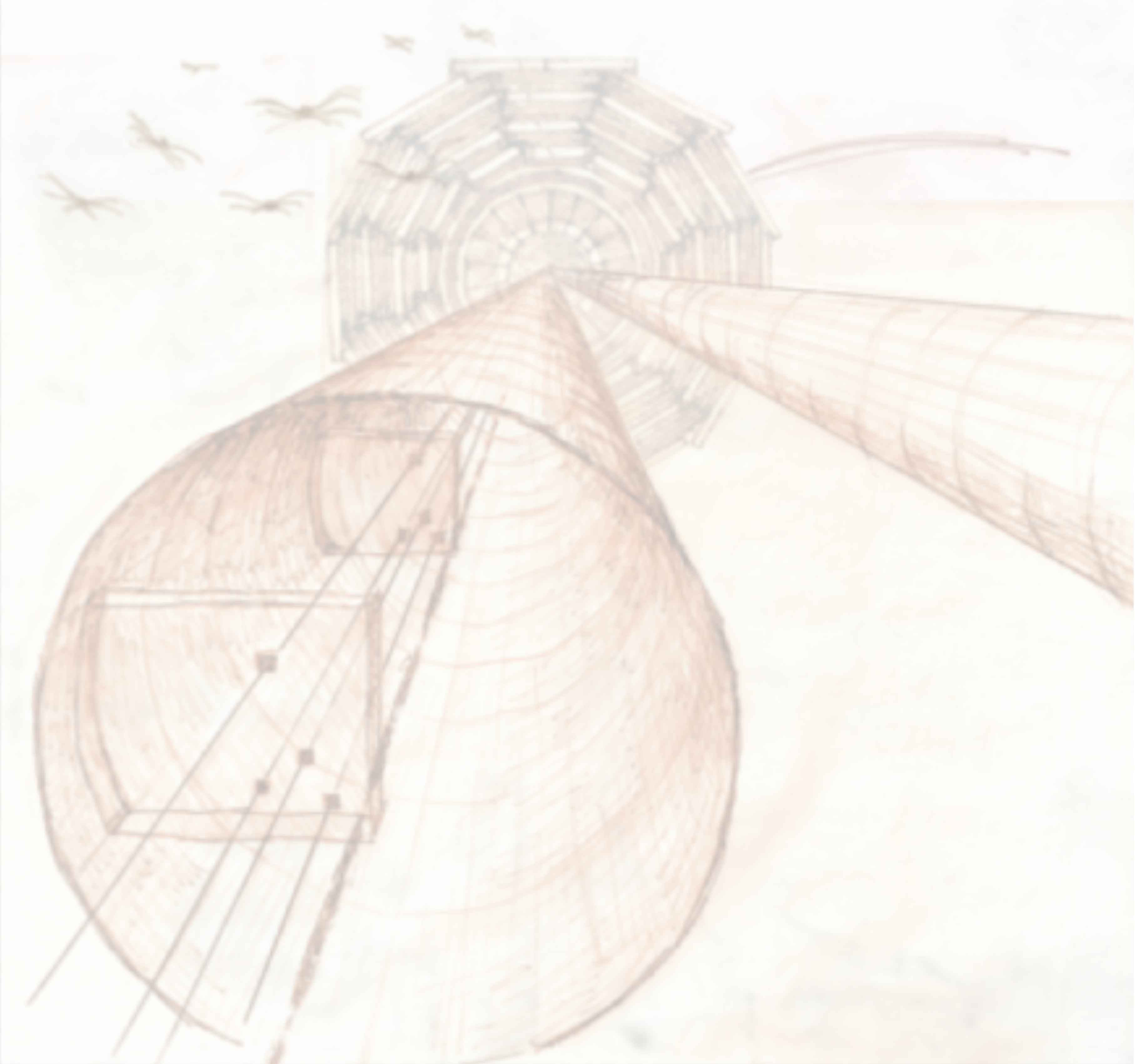
- central production of γγ, WW, ZZ, γZ, $t\bar{t}$
- missing mass searches

Improvements expected in the reconstruction of proton kinematics

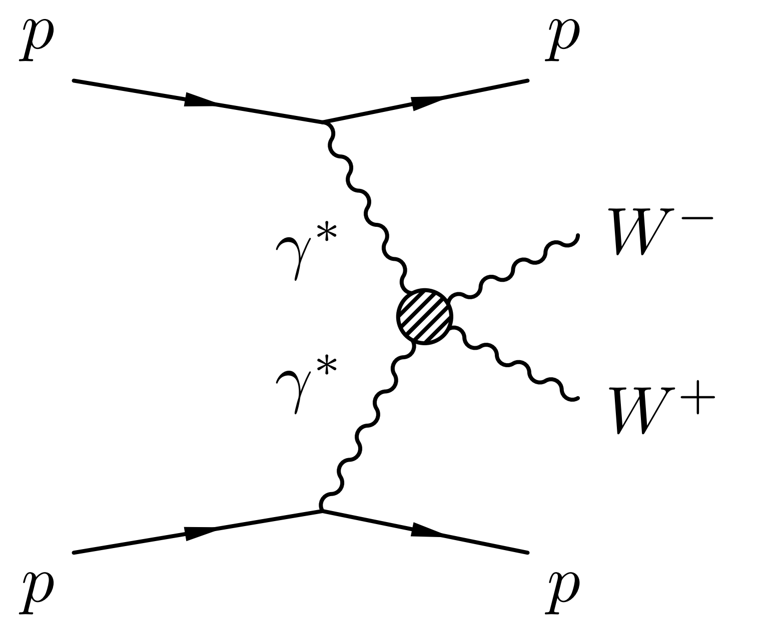
Detector construction started for LHC Run 3 (2021-2023)

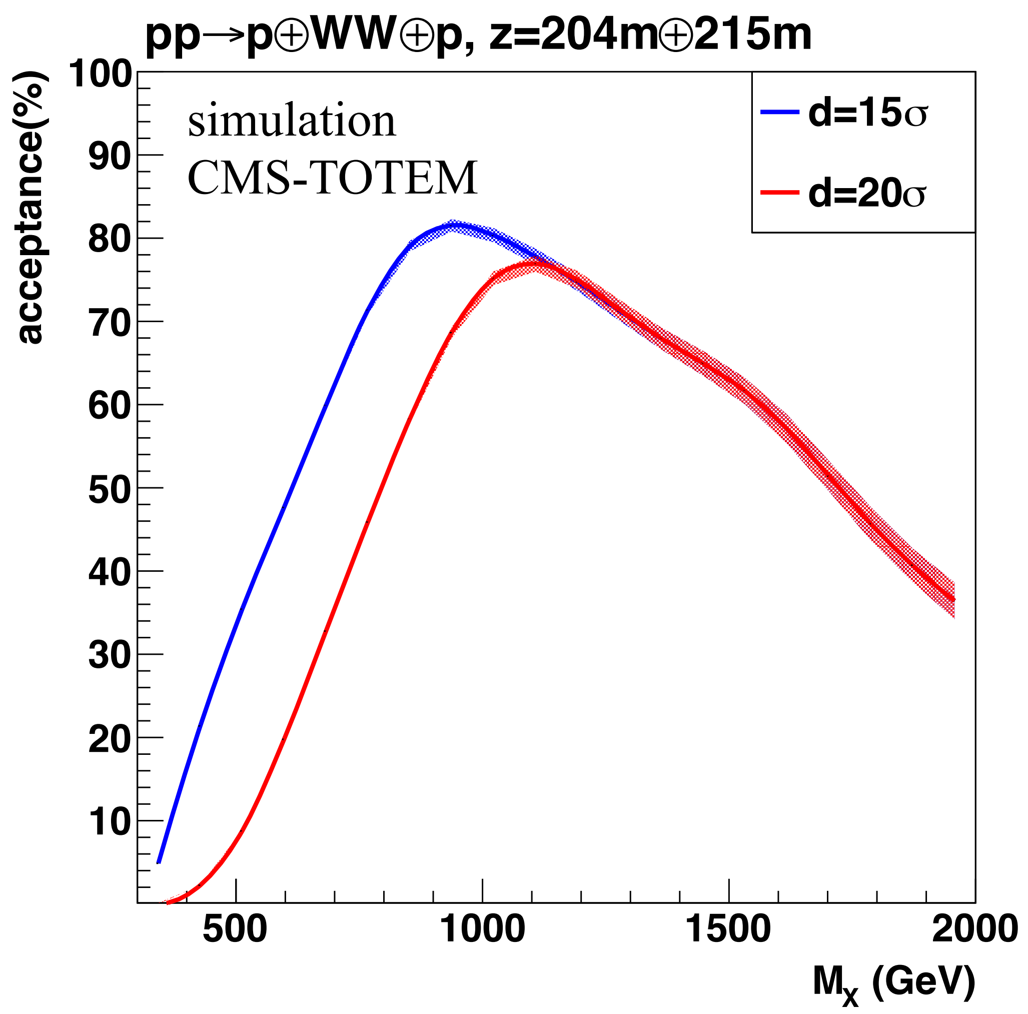
- goal: ~300 fb^{-1}

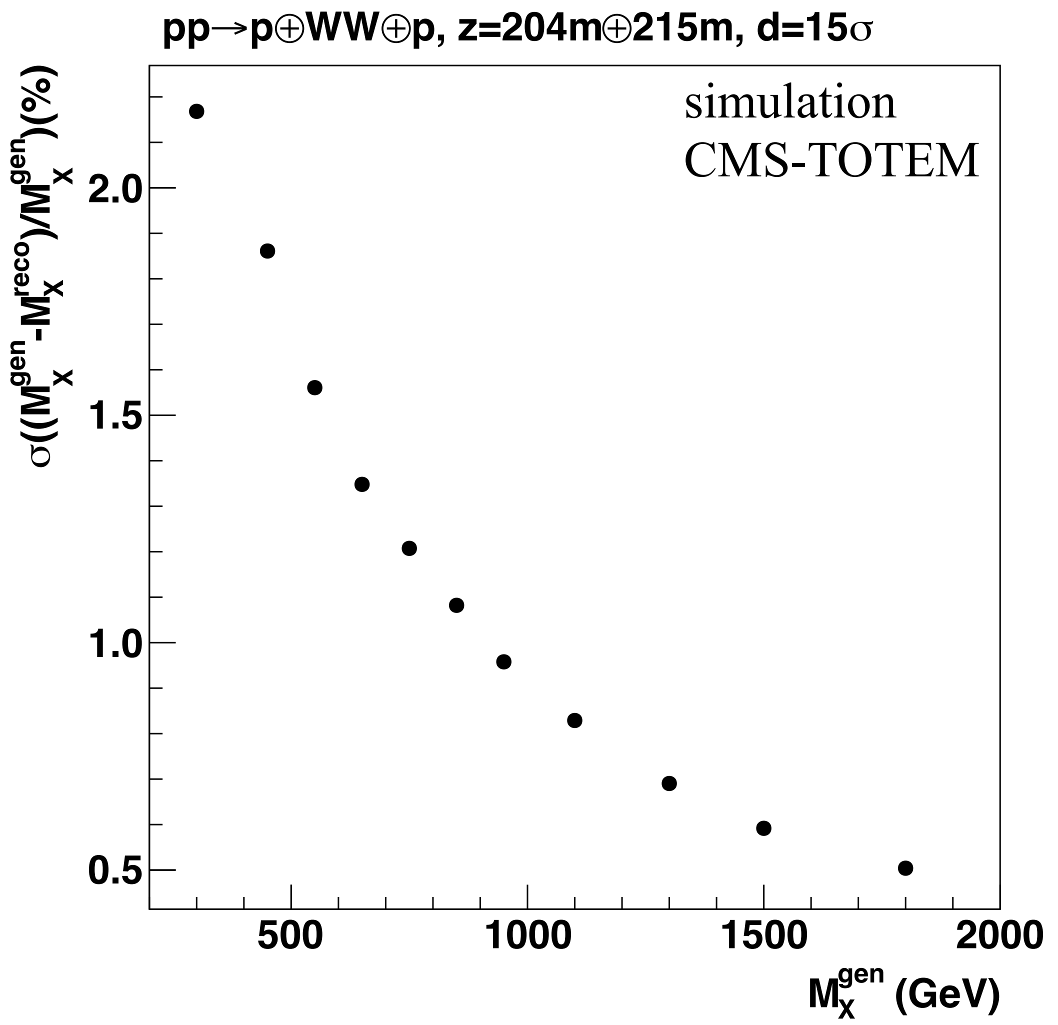
Additional material

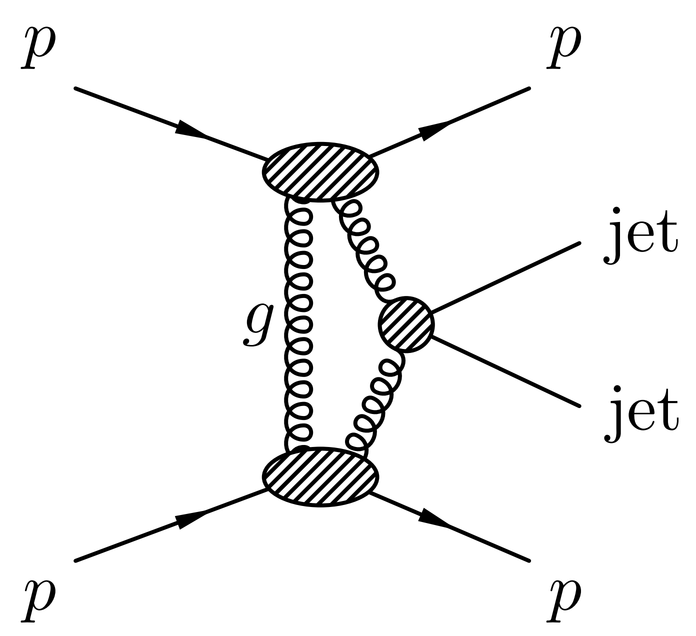


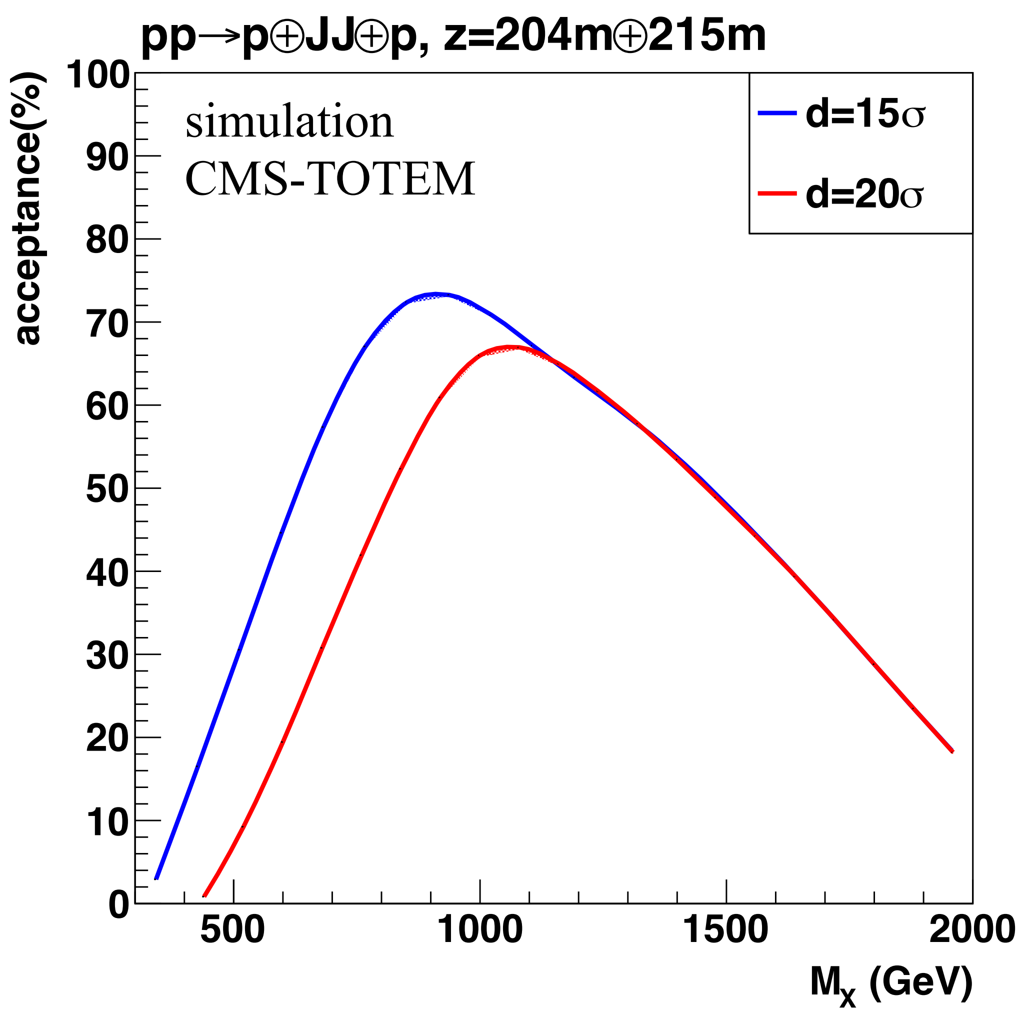
M_X acceptance and resolution

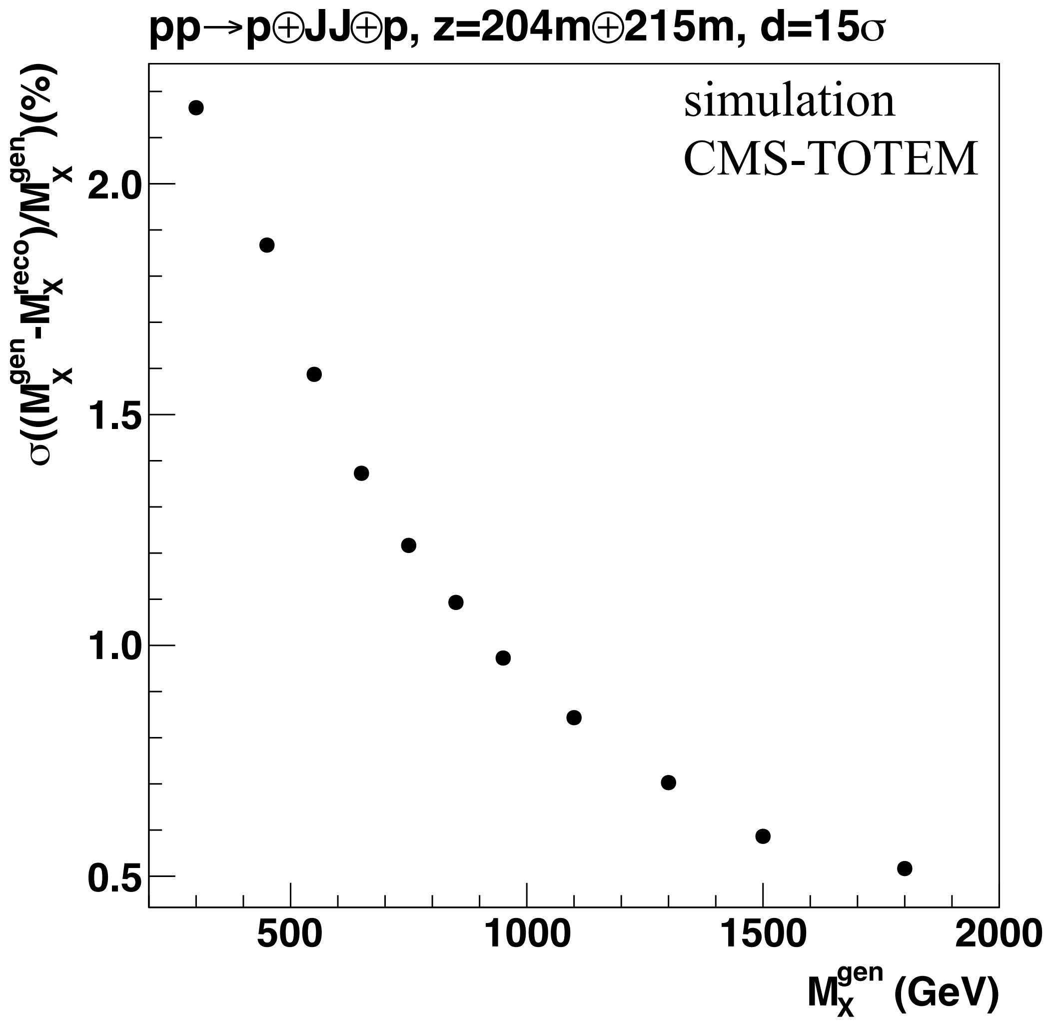












(from the TDR)

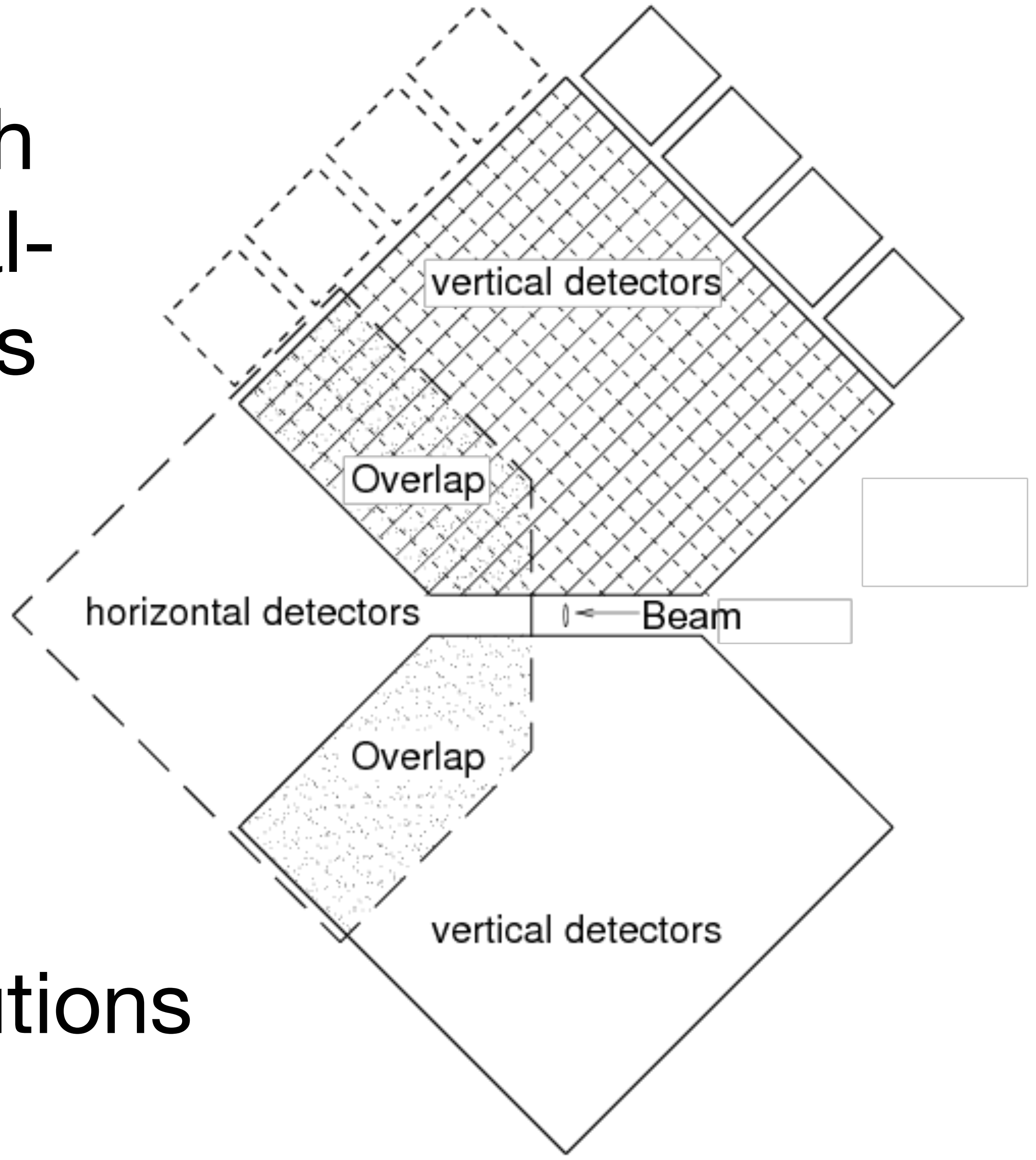
Detector alignment

Procedure developed and used extensively by TOTEM

CERN-TOTEM-NOTE-2017-001

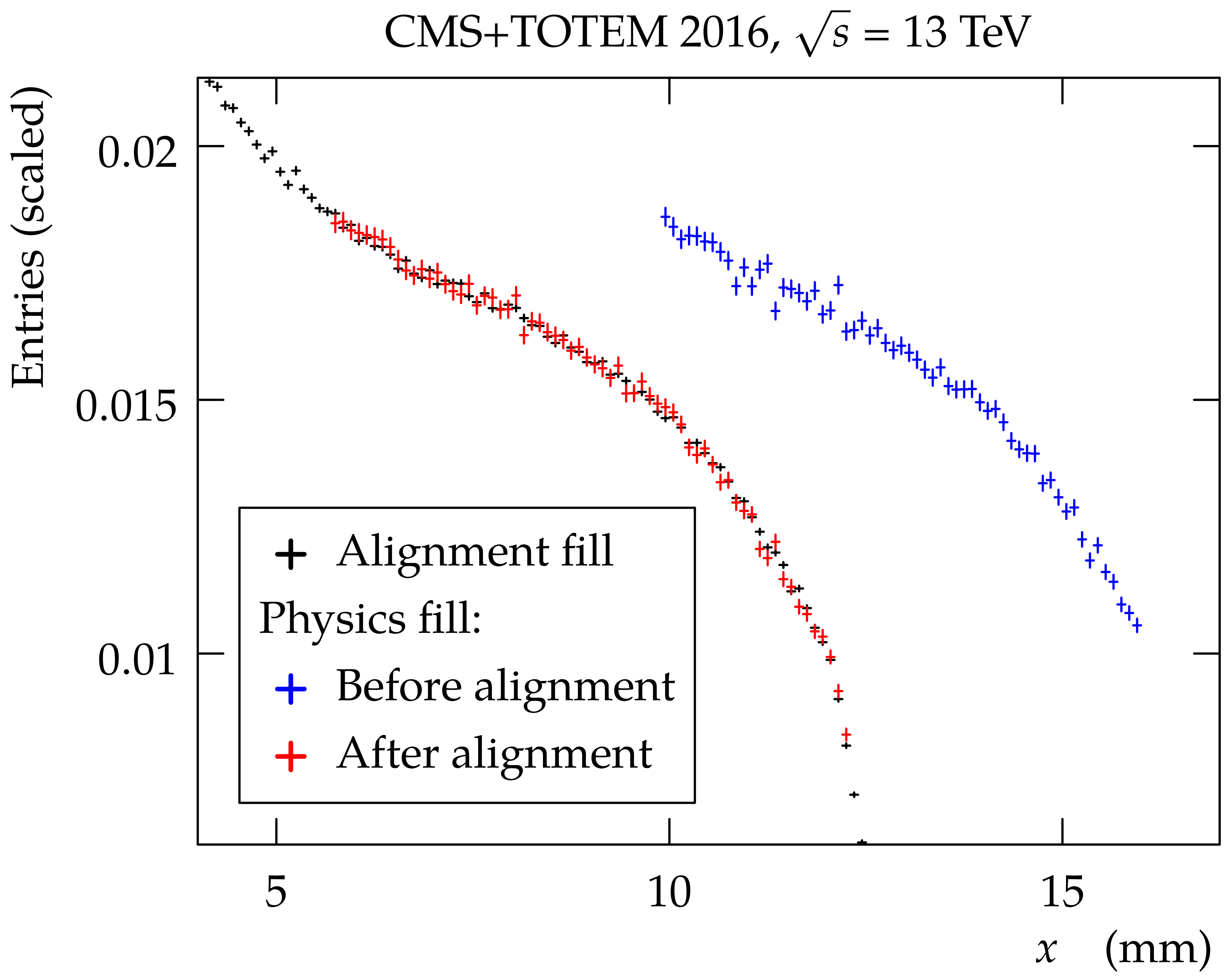
Dedicated alignment fills (low luminosity)

- once per beam optics setting
  1. detector approach to the edge of the scraped beam;
  2. local alignment with overlapping vertical-horizontal detectors (minimise residuals)
  3. alignment with respect to the beam from hit occupancy distributions



Physics fills

- each fill
- match *x* distribution with distribution from alignment fill

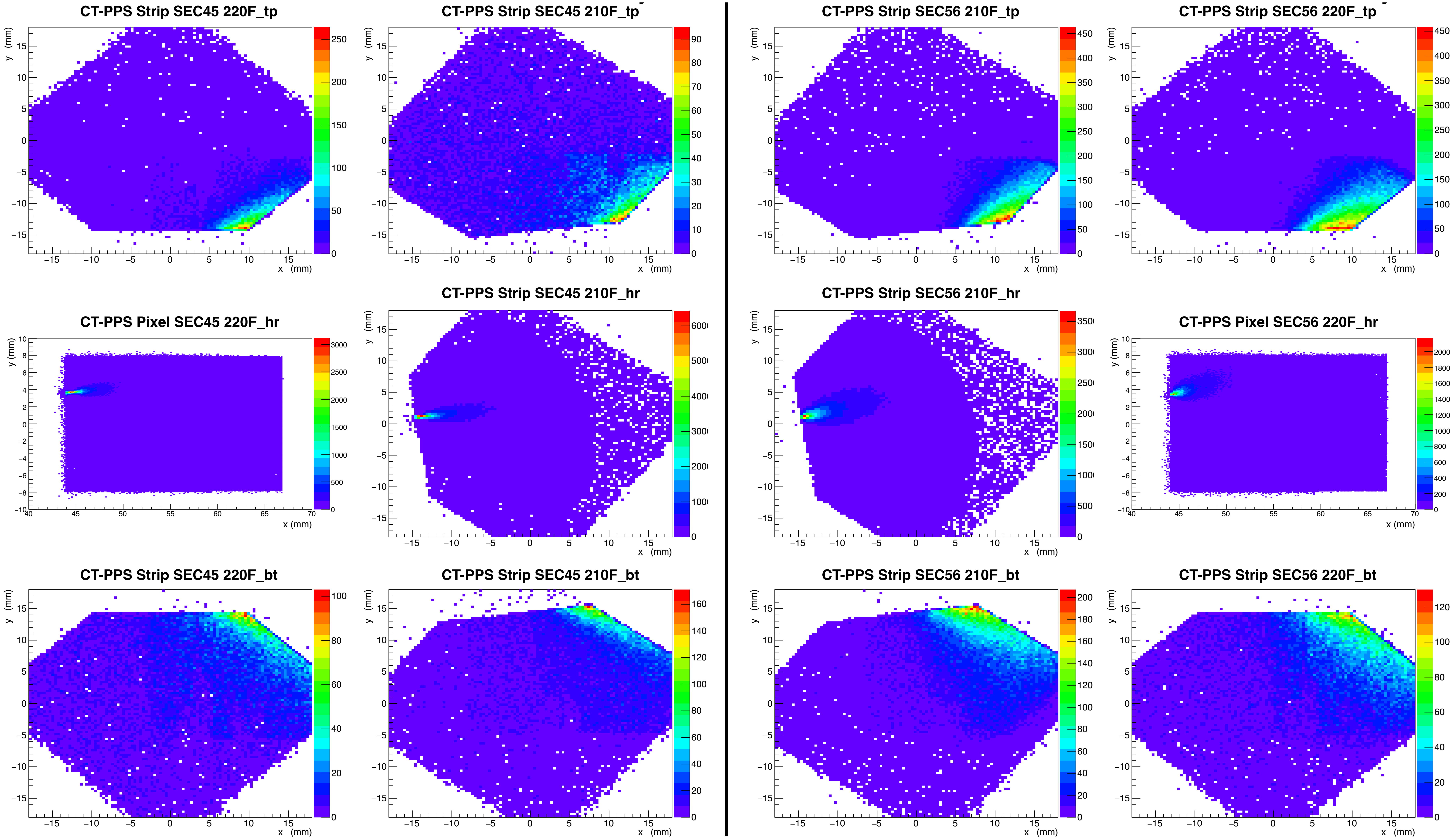


TOTEM and PPS track maps

Alignment run, May 2017

Sector 45 | Sector 56

Top | Horizontal | Bottom



Top | Horizontal | Bottom

Dilepton kinematics distributions